Converge

ANSYS

Application of ANSYS Workbench & CFX at NASA's John C. Stennis Space Center

Jody L. Woods
Systems Analysis & Modeling

NASA John C. Stennis Space Center

2007 ANSYS U.S. Regional Conference Series

Overview

- SSC Background Info
  - Who We Are & What We Do
  - Test Facilities / Capability
- Analysis Activities at SSC
  - Systems Analysis & Modeling
    - Diverse Range of Analysis Types
    - Analysis Tools Used
- ANSYS Workbench / CFX Applications
  - Recent Examples of ANSYS Workbench Analyses
  - Future ANSYS Workbench & CFX Capability Assessment

Stennis Space Center Background Info

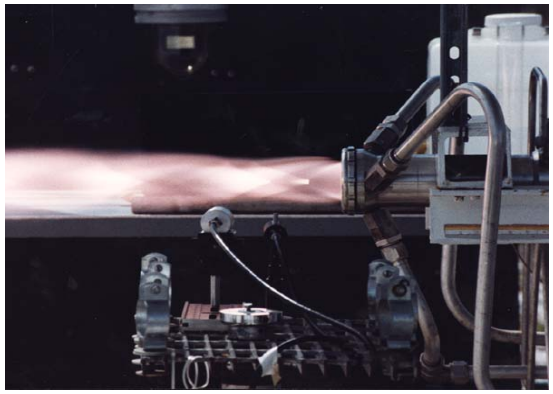
SSC – Who We Are & What We Do

Stennis Space Center

One of NASA's 10 Field Centers; The Nation's Premier Rocket Propulsion Test Facility and Home to the Applied Research & Technology Office

- **Engineering & Science Directorate (E&SD)**
  - Responsible for the safe operation of one of a kind national test facilities valued at over $2 billion
  - Oversight of several rocket engine propulsion test programs such as Space Shuttle Main Engine acceptance testing and Constellation Systems J-2X engine testing for NASA's next generation of rockets for Lunar and Mars exploration
- **Applied Research & Technology Project Office (ARPTO) and the Science and Technology Division (S&TD)**
  - Conducts scientific research focused on extending results of NASA Earth-Sun system sciences beyond science and research communities to contribute to national priority applications with societal benefits
  - Maintains scientific and engineering laboratory capabilities to support ocean color remote sensing, calibration/validation for coastal remote sensing and modeling products, algorithm development, and sensor development to support scientific and propulsion testing applications
- **Innovative Partnership Program (IPP)**
  - Consists of Small Business Innovative Research and Small Business Technology Transfer (SBIR/STTR) programs, Intellectual Property Management (IPM), and the Dual-Use Technology Development Program
  - Provides leveraged technology investments, dual-use technology partnerships, and technology solutions for NASA through partnerships with industry, academia, and other agencies

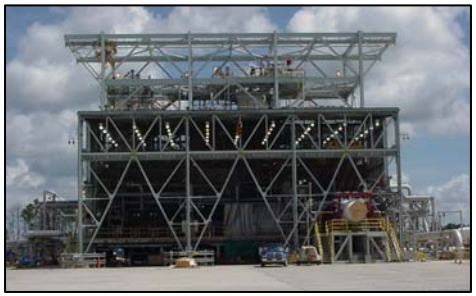
SSC Tests A Wide Variety of Engines and Test Articles over a Broad Range of Test Propellant Conditions, Facilities, and Configurations



SSC – Complete Suite of Test Capability and Expertise at One Site

Stennis Space Center

SSC Rocket Propulsion Test Facilities



E-1 Test Stand

- 3 Test Cells
- Ultra High Pressure Blow-Down Propellant Delivery (15k psi)
- Full-Scale Engines & Components (Up to 1.2M lbf Thrust)

E-2 Test Stand

- 2 Test Cells
- Ultra High Pressure Blow-Down Propellant Delivery (15k psi)
- Mid-Scale & Small-Scale Engines & Components (Up to 120K lbf Thrust)

E-3 Test Stand

- 2 Test Cells
- High Pressure Blow-Down Propellant Delivery
- Small-Scale & Sub-Scale Engines & Components (Up to 60K lbf Thrust)

A-1 & A-2 Test Stands

- 1 Test Cell Each
- Low Pressure Run Tank Propellant Delivery Full-Scale Engine Development & Certification (Up to 1.7M lbf Thrust)

B-1/B-2 Test Stand

- 2 Test Cells
- Low Pressure Run Tank Propellant Delivery
- Full-Scale Engine / Stage Development & Certification (Up to 11M lbf Thrust)

SSC – Complete Suite of Test Capability and Expertise at One Site

Stennis Space Center

SSC Rocket Propulsion Test Support Facilities

Cryogenic Propellant Storage Facility

Six 100,000 Gallon LO2 Barges
Three 240,000 Gallon LH2 Barges
600,000 Gallon LH2 Storage Sphere

High Pressure Industrial Water (HPIW)

330,000 gpm Delivery System

High Pressure Gas Facility (HPGF)

GN, GHe, GH, Air: ~ 3000 to 4000 psi

Additional Support

- Laboratories
  - Gas and Material Analysis
  - Measurement Standards and Calibration
  - Environmental Measurements & Analysis
- Fabrication & Maintenance Shops
- Site Utilities

Analysis Activities at SSC

SSC – Systems Analysis & Modeling

Stennis Space Center

- **Diverse Range of Problems Analyzed to meet Responsibilities for Facility and Test Program Design, Operations, and Maintenance**
  - **Structural:** Piping Systems, Components, and Test Stand Structures, Linear & Non-Linear Stress, Modal, Structural Dynamics, Contact, Structural Stability
  - **Fluids:** Liquids, Gases, -420°F to 6000°F+, Near Vacuum to Ultra High Pressures, Incompressible, Compressible, Piping Networks, Complex 3D Internal and External Flows, Chemical Reactions, Cavitation, Flow Instabilities, Multi-Phase Flow, Boiling , Free Surfaces
  - **Thermal:** Structural Heat Xfr with Conduction, Convection, and Radiation, Piping System Network Analysis
  - **Multi-Physics:** Thermal Stress, Conjugate Heat Xfr Involving Conduction and Radiation, Fluid Structure Interaction
- **We have developed a suite of effective analytic modeling and analysis tools providing high fidelity assessment of test stand performance; our tools include:**
  - Rocket Propulsion Test Analysis (RPTA) Model, a 1D propellant system analyzer
  - Spreadsheet & MathCad-Based Analysis Routines for Orifice Sizing, Pressure Drop/Valve Sizing & Protuberance Analysis (RTD in Pipes), etc.
  - Piping Network Flow & Heat Transfer Analysis (FlowMaster, SINDA)
  - Piping System Structural & Code Compliance Analysis (AutoPIPE)
  - ***CFD Used for Select Propulsion Test Situations*** (CRUNCH, ***CFX***)
  - ***Finite Element Structural, Thermal, and Multiphysics Analysis (ANSYS/CFX)***
- **Growing our Capabilities**
  - **Procured ANSYS Mechanical, Pro-Engineer Import Module and 1 year lease of CFX Mesh , CFX Full Capability Solver, CFX Post, and CFX Parallel in Oct. '06**
    - "Filled the Gaps" in our analysis tool suite
    - Assess CFX & Workbench/CFX capabilities relative to our needs

ANSYS

SSC – Integrated Facility Simulation & Analysis

Stennis Space Center

Where We Are Now

Design & Analysis *FY-06/07 Capability Development Initiatives*

ANSYS Is a Significant Component in SSC's Analysis Tool Suite

Strengthening/Broadening Range of Engineering Staff Competencies

- Structural Analysis
- Thermal Analysis/Heat Transfer
- Control Systems design/development
- Fluid Mechanics specific to RPT

Where We Were Before '06

- **RPTA Model**
- **CFD Crunch/FDNS**
- **Fanno Model**
- **MathCad/Excel Models**
- **AutoPIPE Piping Systems**

EA30

Analysis Tool Suite Growth

- **ANSYS Workbench with CFX**
  - Structural Stress & Thermal Analysis
  - Piping System and Test Stand Modal and Dynamics Analysis
  - Conjugate Heat Transfer Analysis
  - Fluid Structure Interaction Analysis
  - Advanced Computational Fluid Dynamics Analysis
- **FlowMaster by FlowMaster, Inc.**
  - Purge systems design and analysis
- **SINDA**
  - System Network Thermal Analysis

Test Data Analysis Process Improvements

- Improved DDMS
  - **Record Retention System Development**
  - **Drawing Tree Development**
  - **Pro/E model MSK capability**
    - A CM enhancement opportunity
- Wider (Extra-EA30) access to analytic models
  - **PITV Project**
    - GUI
    - Server Access
- Instituted EA30 Internal Technical Reviews

Broader/More Comprehensive Engineering Support

- A&B Stand Modeling & Analysis
- Operations Support
  - Activation & Test
- Facility Operations Support, e.g., in FY06
  - LH2 Barge RD issue
  - HP Air System Contamination
  - LH2 Sphere Bypass Design
  - UT inspection of B Stand HP Water Deluge Sys
  - E1 LO2 Butterfly Valve Investigation

Expanding Beyond SSC E-Complex

- PBS B2 Test Stand Design
- KSC LO2 Tank Analysis
- RS-68 Test vs. Flight Performance Variation

ANSYS Workbench with CFX Promises a Substantial Increase in Physics Based Analysis Capability

SSC – Integrated Facility Simulation & Analysis

Stennis Space Center

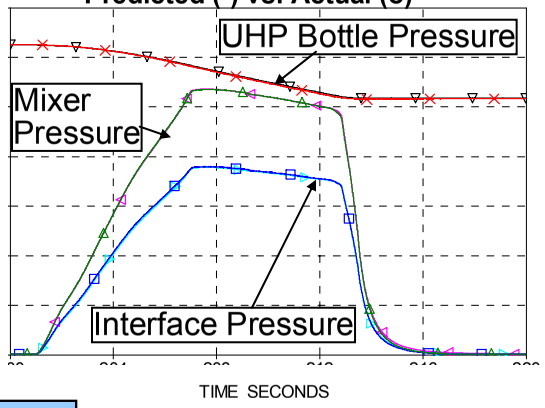
Analytical Tools Available for Test Facility/Project Analysis, Simulation, & Modeling

- Comprehensive Propellant System Thermodynamic Modeling & Test Simulation
- Comprehensive Structural / Thermal / Fluids Modeling Expertise & Capability

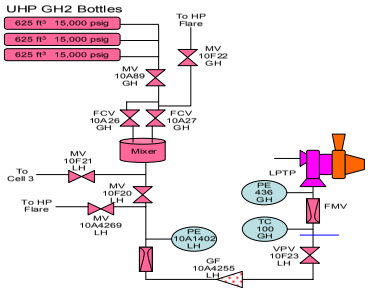
Integrated Performance Modeling Capabilities Substantially Improves Understanding & Knowledge of Test Systems Performance that has Translated to Efficient Test Facility Design, Activation, & Test Operations

Test & Data Analysis; Model Verification & Validation

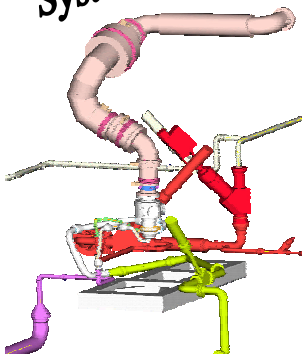
Predicted (-) vs. Actual (o)



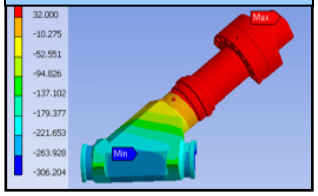
System Design



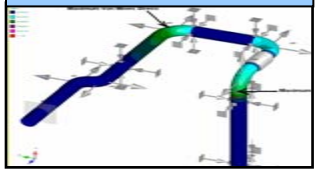
System Modeling



Coupled Field / Multiphysics Analysis

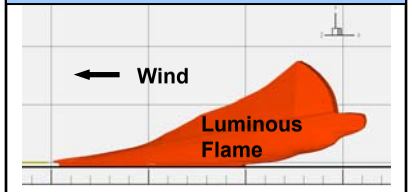


Structural Stress, Dynamics, and Heat Transfer Analysis



Fluid, Thermal, and Thermodynamic System Network Analysis

CFD Modeling & Analysis



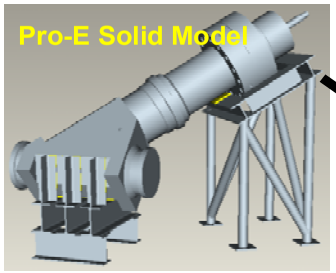
Recent Examples of ANSYS Workbench Analyses

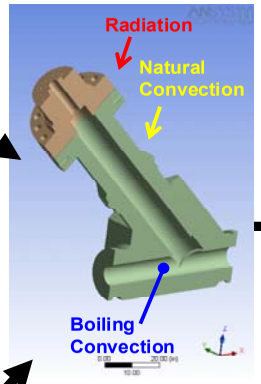
SSC – Examples of ANSYS Workbench / CFX Analyses

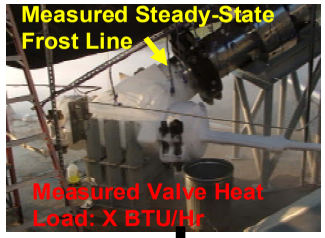
14” LOX Valve Thermal Analysis

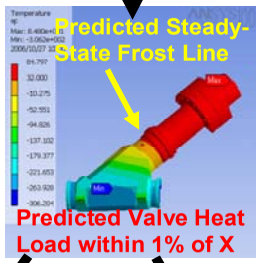
- **26,000 lb LOX Valve for flow isolation of Ultra High Pressure LOX system**
- **Valve was cryo flow tested prior to installation in order to mitigate costly installation & removal if it did not work correctly**
  - FE thermal-structural model developed to validate ANSYS with cryo flow test data and assist in redesign

Geometry Description → Analysis Model → Loads & Boundary Conditions → ***Validated Results, thus Methodology Validated***

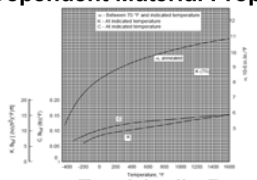




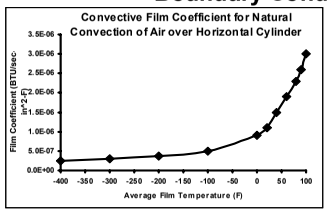


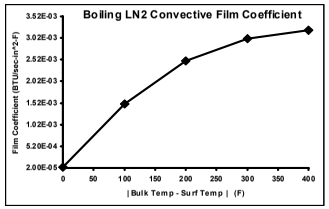


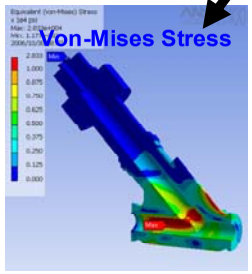
NIST / MIL-HDBK Temperature Dependent Material Properties

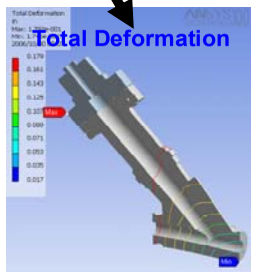


Empirically Based Temperature Dependent Boundary Condition Parameters







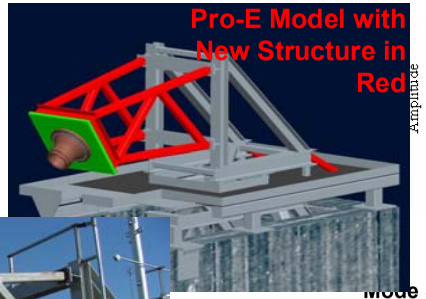


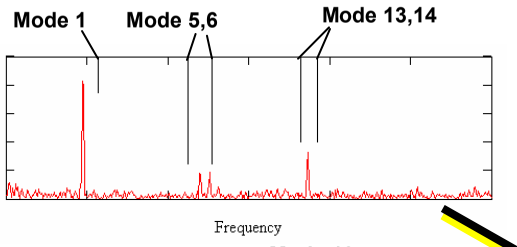
SSC – Examples of ANSYS Workbench / CFX Analyses

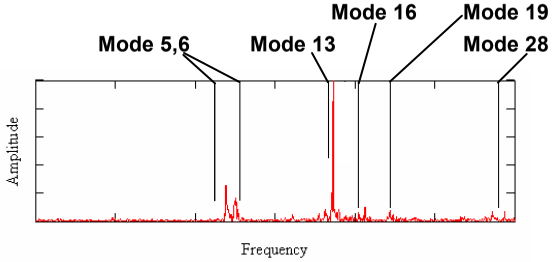
Stennis Space Center

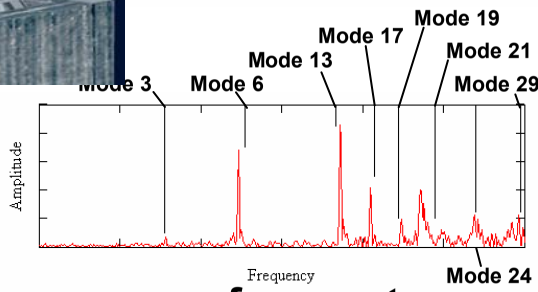
Thrust Takeout Structure Modal Analysis

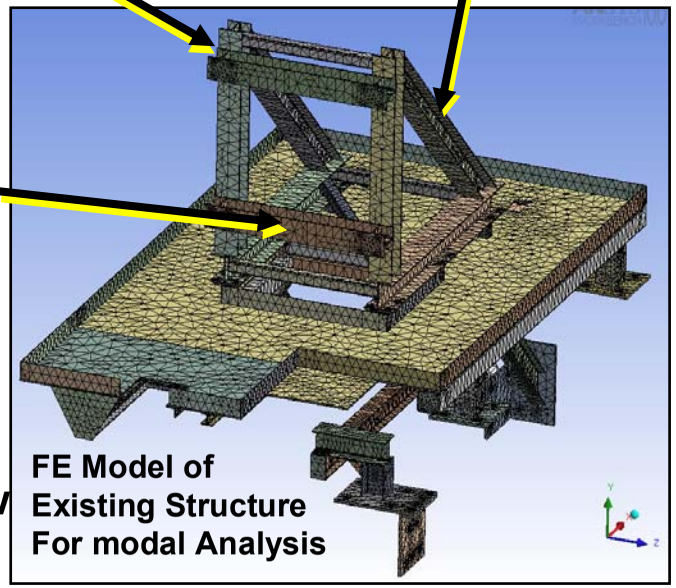
- Existing thrust take-out structure being modified for new test program
- Customer needed natural frequency predictions for modified structure
- Developed ANSYS Workbench models of current and new structure for modal analysis











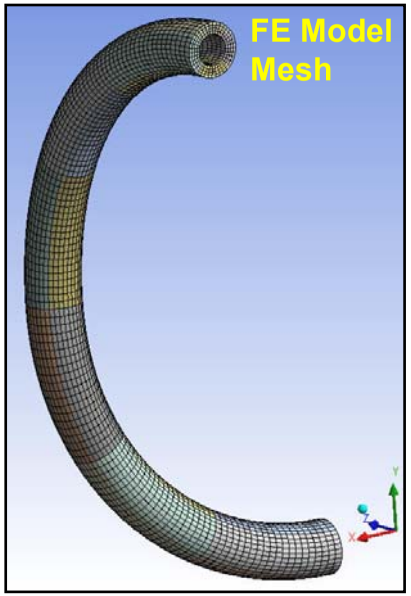
- Measured frequency response of current structure to impact loading at specific locations
  - Overall agreement with prediction was good
- Validation of model with experimental data added level of confidence to predictions for new structure

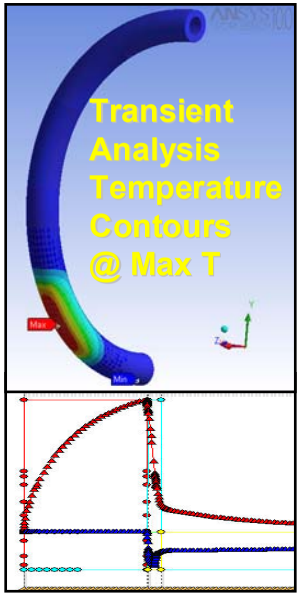
SSC – Examples of ANSYS Workbench / CFX Analyses

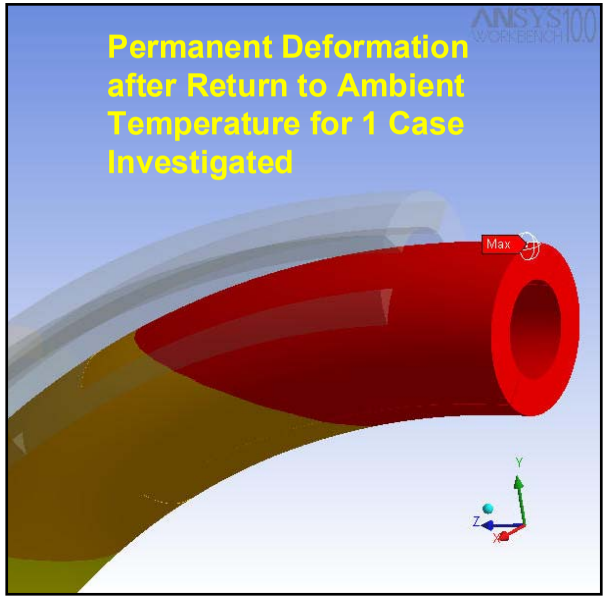
Stennis Space Center

Ultra High Pressure (15K psi) GN2 Spool Piece Misalignment

- Double 90° bend spool-piece for new UHP GN2 Bottle didn't line up
- Proposed mitigation was to heat specific area in the field such that resulting permanent deformation would result in alignment after return to ambient temperature
- ANSYS Workbench used to conduct transient thermal and plastic deformation analyses for several sets of process parameters, i.e. location and area of heat application, duration, max temperature, etc.
- Determined that proposed method would be infeasible
  - Attaining desired deformation would require complex and precise process parameters, multiple locations of heat application, and post-operation stress relief heat treatment
  - Recommended cut-and-weld procedure to achieve precise alignment







ANSYS

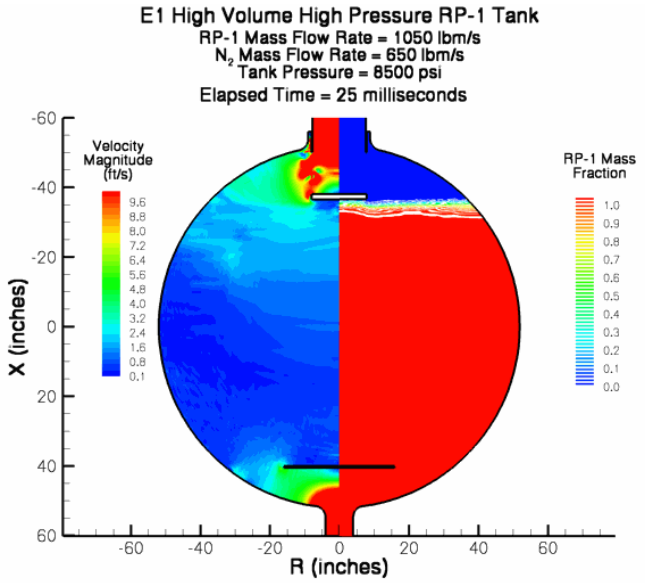
Planned
ANSYS Workbench / CFX
Capability Assessment

SSC – Planned Future ANSYS Workbench / CFX Analyses

Stennis Space Center

Blow-Down Run Tank Cryo-Collapse & Propellant Contamination

- **Blow-Down Run Tanks supply propellant to tests; as pressurant is fed in through the top, the propellant is forced out the bottom**
  - Cryo-Collapse is sometimes exhibited
  - Propellant Contamination occurs
- **Analyzing and predicting these phenomena is very complex**
  - Heat Transfer between walls and fluid and between gas and liquid
  - Multi-Phase with transition from superheated gas to compressed liquid and the reverse
  - Going from ambient pressure, sub-critical conditions to ultra-high pressure super-critical
  - Free surface and droplets when sub-critical
  - Heat transfer associated with boiling, condensation, and vaporization
- **In-House CFD tools don't capture all applicable physics**
  - ANSYS/CFX will be used to check in-house code results



SSC – Planned Future ANSYS Workbench / CFX Analyses

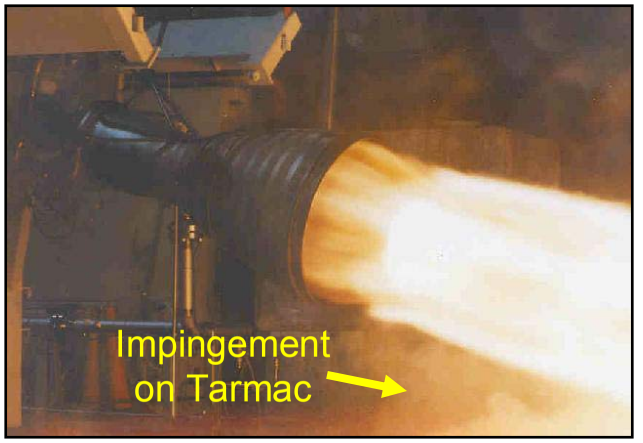
LH2 Storage Sphere Boil Off

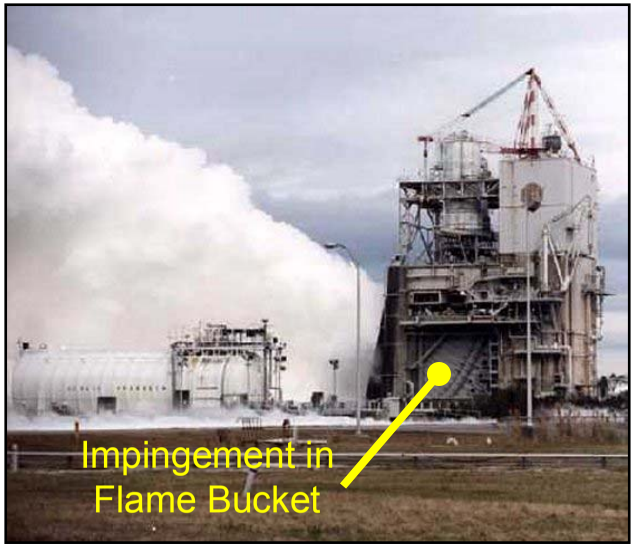
- **50,000 Gallon Vacuum Jacketed LH2 Storage Sphere**
  - Low pressure inner tank supported with light stand-off structure
  - Perlite fill within vacuum jacket suppresses radiative heat transfer between inner and outer tanks; Perlite settling results in area at top of tank with full radiative heat transfer
  - Constant GH2 boil-off due to heat leakage into LH2
  - At low fill levels significant thermal gradient may exist between tank bottom and top; could result in damage to support structure and shifting of perlite and/or inner tank
- **Need to determine if there exists a minimum critical tank fill level that precludes excessive tank support stress from thermal gradients**
  - Conjugate heat transfer analysis with liquid, gas, and solid domains involving conductive, convective and radiative heat transfer
  - Boiling liquid and temperature stratification of gas within inner tank
  - As LH2 boils off and lowers fill level, assess σ and δ vs. fill level

SSC – Planned Future ANSYS Workbench / CFX Analyses

Plume Impingement Heating with Water Cooling

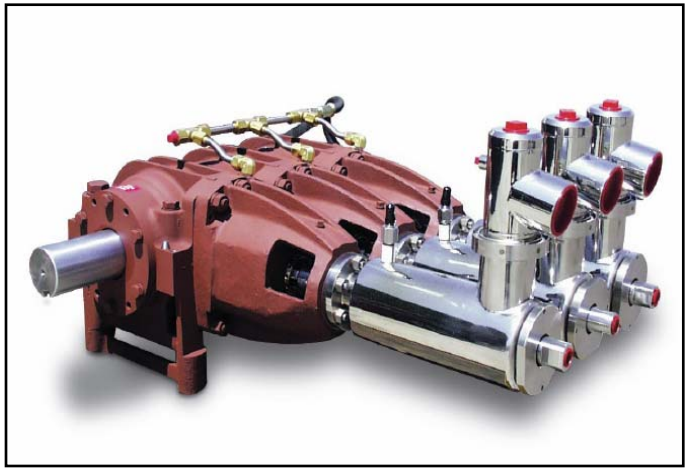
- **Rocket Engine exhaust plumes often impinge on concrete tarmac or a steel "flame bucket" that redirects a vertical plume horizontally**
  - Water cooling is required in areas of impingement
- **Capability needed to rapidly and accurately predict amount of cooling water required, adequate injection hole pattern, heat load on structures, etc.; particularly for new test programs / new construction**
  - Conjugate heat transfer including radiation
  - Subsonic & supersonic flow
  - Chemically reacting flow
  - Multiphase flow with boiling





LN2 Pump Parametric Study

- **Existing positive displacement LN2 pump system at High Pressure Gas Facility does not perform to specifications and requires excessive maintenance; slated to be replaced with new equipment**
- **Pumping efficiency very sensitive to fluid quality due to vaporization / cavitation of fluid within cylinders on inlet stroke**
  - Results in less than positive displacement performance
  - Results in excessive heating of fluid and wear of components
- **Parametric study using ANSYS proposed in order to arrive at best design given the range of fluid inlet conditions expected**
  - Conjugate heat transfer
  - Fluid structure interaction
  - Multiphase flow with cavitation
  - Parameterized bore, stroke, RPM, etc.; Range of fluid inlet conditions
  - Assess pumping efficiency vs. parameters to arrive at optimum design



Application of ANSYS Workbench & CFX at NASA's John C. Stennis Space Center

Summary

- **NASA's John C. Stennis Space Center – Who we are & What We Do**
  - The Nation's Premier Rocket Propulsion Test Facility; We Test A Wide Variety of Engines and Test Articles over a Broad Range of Test Propellant Conditions, Facilities, and Configurations
- **Analysis Activities at SSC**
  - Diverse Range of Problems Analyzed to meet Responsibilities for Facility and Test Program Design, Operations, and Maintenance
  - We have developed a suite of effective analytic modeling and analysis tools
  - Growing our capabilities; acquired ANSYS Workbench / CFX as part of development initiative
- **Examples of tasks already undertaken using ANSYS Workbench**
  - Thermal / Structural Analysis Validated with Experimental Data
  - Modal Analysis Validated with Experimental Data
  - Transient Heat Transfer and Thermal Stress with Plastic Deformation
  - ***ANSYS Workbench has been very useful and has lived up to expectations***
- **Examples of capability evaluation planned using ANSYS Workbench & CFX**
  - Conjugate Heat Xfr with Multiphase flow, very complex thermodynamics, liquid free surface and droplets; physics not solvable by in-house CFD codes
  - Conjugate Heat Xfr w/ Radiation / Thermal Stress, Multiphase Flow, Boiling, Buoyancy
  - Conjugate Heat Transfer Xfr w/ Radiation, Multiphase Flow, Boiling, Subsonic & Supersonic Flow, Chemically Reacting Flow
  - Parametric Study involving Conjugate Heat Transfer, Multiphase Flow with Cavitation, and Fluid Structure Interaction

Questions / Discussion

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